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**TILED PROJECTION DISPLAY USING SPATIAL LIGHT
MODULATORS**

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**TILED PROJECTION DISPLAY USING SPATIAL LIGHT
MODULATORS**

FIELD OF THE INVENTION

This invention generally relates to projection imaging apparatus
5 and more particularly relates to an apparatus and method for tiled projection
display using spatial light modulators.

BACKGROUND OF THE INVENTION

There is a recognized need for wide-screen electronic displays in a
number of fields, with typical uses ranging from desktop computer applications, to
10 visualization and design software, to diagnostic imaging equipment, to still and
motion picture entertainment systems and advertising displays, for example. In a
recent paper entitled “DSHARP – A Wide Screen Multi-Projector Display” by
Gary K. Starkweather in SID Digest 2003, potential advantages of wide-screen
electronic displays for workstation environments are enumerated, including
15 improved productivity and efficiency, minimized “household” chores for desktop
organization, improved adaptability to the human visual system, and improved
task comprehension.

With existing projection display systems, both film-based and
electronic, images can be projected only at limited sizes and aspect ratios. These
20 conventional display sizes are not sufficient to provide large-scale wide-screen
display systems based on a single image-forming component. While there have
been attempts to fabricate large-scale electronic spatial light modulators,
exceeding conventional image frame sizes has proved difficult in practice.
Instead, schemes for tiling multiple display systems have been adapted to
25 overcome size and aspect ratio limitations.

Tiling solutions for conventional projection systems have been
successfully implemented with various configurations. Tiling arrangements using
conventional displays are disclosed in a number of publications, including the
following:

- 30 • “DottyToto: A Measurement Engine for Aligning Multi-projector Display
Systems” by Mark Hereld, Ivan R. Judson, and Rick Stevens in Projection

Displays IX, Proceedings of SPIE-IS&T Electronic Imaging, Ming H. Wu, editor;

- “Immersive Planar Display Using Roughly Aligned Projectors” by Ramesh Raskar, The Office of the Future Group, University of North Carolina at Chapel Hill; and
- “Multi-Projector Displays Using Camera-Based Registration” by Ramesh Raskar et al., Department of Computer Science, University of North Carolina at Chapel Hill.

These and other display tiling solutions operate by attempting precision alignment between projected images from multiple projectors. However, this type of solution is hampered by effects such as slight movement of the display screen, jarring or movement of one or more projection apparatus, expansion due to heat, and imperfections due to projection optics, such as keystone effects, for example. Moreover, slight color changes in adjacent tiled image sections become readily noticeable, detracting from the intended effect of projection image tiling. Among solutions proposed for tiling projection apparatus with minimal visibility of tile borders are those proposed in U.S. Patent No. 6,590,621 (Creek et al.) and U.S. Patent No. 6,513,938 (Kubota et al.)

Tiling has been used for spatial light modulators used in backlighting display applications. For example, U.S. Patent No. 6,262,696 (Seraphim et al.) discloses a large display panel having a number of precisely aligned LCD display modules arranged as tiles over a backlighting surface; U.S. Patent No. 5,626,410 (Chambers et al.) discloses tiling of LCD devices in a backlighting display using a fiber optic array for achieving more uniform brightness; U.S. Patent No. 5,902,030 (Blanchard) discloses a backlighting system using multiple projectors, with a screen outfitted for suitably combining images, such as using Fresnel lens. While these approaches offer some solutions for backlighting systems that form an image on a specially designed, diffusive surface, the apparatus and techniques of these patents are not suitable for front-projection systems.

Tiling approaches have been proposed for printing applications. For example, commonly assigned U.S. Patent No. 6,580,490 (Wong et al.)

discloses the use of multiple tiled LCD spatial light modulators for providing exposure energy to a photosensitive medium over an enlarged two-dimensional area. However, print requirements vary significantly from projection requirements, requiring different solutions for uniformity, resolution, luminous flux, contrast, imaging artifacts, and other image characteristics.

There have been a number of proposed projection systems using multiple spatial light modulators and combining output beams, centered on a single optical axis for projection as a single output beam. For example, commonly-assigned U.S. Patent No. 6,585,378 (Kurtz et al.) discloses a full-color projection system that employs a separate spatial light modulator in each color path, one each for red, green, and blue light modulation. Modulated light beams from these devices are then overlapped, typically using a polarization beam splitter, an x-cube, or other component as a beam combiner to provide the composite color image. Similarly, U.S. Patent No. 5,788,352 (Montroy et al.) discloses the use of two LCD spatial light modulators to form overlapping images, providing increased luminance and resolution and improved response time. However, the arrangements disclosed in U.S. Patent No. 6,585,378 and U.S. Patent No. 5,788,352 are directed to overlapping of images formed on separate spatial light modulators rather than to tiling images adjacently to increase the size of the projected image.

Thus, it can be seen that tiling arrangements using multiple spatial light modulators have been adapted for a small number of backlit display and print imaging applications. However, projection display apparatus employing LCD spatial light modulators present some significant challenges to tiling implementation. For example, polarization states of incident illumination and modulated light must be accounted for in many types of projection apparatus using these devices. Projection optics must be suitable for projecting a tiled display, where tiles are adjacent, rather than overlapping as in the apparatus of U.S. Patent No. 6,585,378 and U.S. Patent No. 5,788,352.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide a projection apparatus and method for forming a tiled display. With this object in mind, the

present invention provides a projection apparatus for forming a tiled image on a display surface, the tiled image comprising at least a first image tile segment and an adjacent second image tile segment, the projection apparatus comprising:

- 5 (a) an illumination system providing a first illumination beam having a first polarization state and a second illumination beam having a second polarization state, the first and second illumination beams being parallel and substantially non-overlapping;
- 10 (b) a first spatial light modulator for forming a first modulated light beam from the first illumination beam;
- (c) a second spatial light modulator for forming a second modulated light beam from the second illumination beam;
- 15 (d) a beam aligner for directing the first and second modulated light beams along adjacent parallel paths, in the direction of the optical axis of a projection lens; and
- projection lens directing the first modulated beam to the display surface to form the first tile segment and directing the second modulated beam to the display surface to form the second tile segment.

20 It is a feature of the present invention that it provides a light-combining mechanism that directs adjacent modulated image beams toward projection optics along parallel paths, allowing projection optics to project a tiled image having two or more adjacent tiles.

25 It is an advantage of the present invention that it obviates the need to align multiple projectors for obtaining a tiled output image. Instead, the apparatus of the present invention can be aligned for tiling at the time of manufacture.

30 It is a further advantage of the present invention that it allows a number of possible arrangements for illumination systems, including the use of the same illumination system for forming multiple tiled images. This helps to provide more uniform color from one tiled image to the next.

These and other objects, features, and advantages of the present invention will become apparent to those skilled in the art upon a reading of the following detailed description when taken in conjunction with the drawings wherein there is shown and described an illustrative embodiment of the invention.

5 **BRIEF DESCRIPTION OF THE DRAWINGS**

While the specification concludes with claims particularly pointing out and distinctly claiming the subject matter of the present invention, it is believed that the invention will be better understood from the following description when taken in conjunction with the accompanying drawings, wherein:

10 Figure 1 is a schematic block diagram showing components of a projection apparatus for forming a tiled image on a display surface in a first embodiment of the present invention, using transmissive spatial light modulators;

Figure 2 is a plan view showing components of the projection apparatus of Figure 1;

15 Figure 3 is a schematic block diagram showing a projection apparatus for forming a tiled image in an alternate embodiment using reflective spatial light modulators;

Figure 4 is a schematic block diagram showing a projection apparatus for forming a tiled image in yet another alternate embodiment;

20 Figure 5 is a schematic block diagram showing a projection apparatus for forming a tiled image in an alternate embodiment using two reflective spatial light modulators; and

Figure 6 is a schematic block diagram showing a projection apparatus for forming a tiled image in another alternate embodiment using two
25 transmissive spatial light modulators.

DETAILED DESCRIPTION OF THE INVENTION

The present description is directed in particular to elements forming part of, or cooperating more directly with, apparatus in accordance with the invention. It is to be understood that elements not specifically shown or
30 described may take various forms well known to those skilled in the art.

In the description that follows, references to components may have part numbers with appended alphabetic characters, where it is useful to describe

specific optical paths, as shown in the accompanying figures. Where the discussion refers to general characteristics of components, rather than to specific optical paths, appended alphabetic characters may be omitted.

First Embodiment

5 Referring to Figure 1, there is shown a projection apparatus 10 for forming a tiled image 12 on a display surface 14. A set of four spatial light modulators 20a, 20b, 20c, and 20d, transmissive liquid crystal devices (LCDs) in a preferred embodiment, is arranged to provide tiled image 12. Each spatial light modulator 20a-20d has a corresponding illumination system 16a, 16b, 16c, and
10 16d for providing source illumination. Possible configurations for illumination systems 16a-16d are given subsequently. The corresponding segment of tiled image 12 (with tiled segments arranged as four contiguous quadrants numbered I, II, III, and IV) is indicated for each spatial light modulator 20a-20d. An arrangement of polarization beamsplitters 22a and 22b with a beamsplitter 30 is
15 provided as a beam aligner 40 for directing a corresponding modulated light beam 26a, 26b, 26c, and 26d from each spatial light modulator 20a, 20b, 20c, and 20d respectively, along a separate path parallel to optical axis O of a projection lens 18. Each spatial light modulator 20a-20d is provided with an analyzer 24a, 24b, 24c, and 24d for improved contrast. (Note that beamsplitter 30 is not a
20 polarization beamsplitter where shown in embodiments disclosed herein.)

Projection lens 18 directs each modulated light beam to a separate tiled segment, as a corresponding one of quadrants I, II, III, or IV. These modulated light beams must be carefully aligned adjacently to minimize gaps, unintended overlaps, or skewing of tiled quadrants I-IV. Figure 1 shows the
25 relative positioning of spatial light modulators 20a-20d and their relative arrangement about beam aligner 40 components from a top view. Figure 2 shows relative positions of spatial light modulators 20a-20d from a side view.

For an understanding of how projection apparatus 10 operates, it is instructive to follow the path of modulated light for each of the four tiled
30 quadrants I-IV in Figure 1, with reference also to the positioning of spatial light modulators 20a-20d from the side view of Figure 2:

- 5 (i) Modulated light for quadrant I from illumination system 16a is modulated by spatial light modulator 20a to form modulated light beam 26a. Polarization beamsplitter 22a and beamsplitter 30 transmit modulated light beam 26a toward projection lens 18, on a path parallel to optical axis O, for forming tiled quadrant I.
- 10 (ii) Modulated light for quadrant II from illumination system 16b is modulated by spatial light modulator 20b to form modulated light beam 26b. Polarization beamsplitter 22a reflects modulated light beam 26b and beamsplitter 30 transmits modulated light beam 26b toward projection lens 18, on a path parallel to optical axis O, for forming tiled quadrant II.
- 15 (iii) Modulated light for quadrant III from illumination system 16c is modulated by spatial light modulator 20c to form modulated light beam 26c. Polarization beamsplitter 22b reflects modulated light beam 26c and beamsplitter 30 reflects modulated light beam 26c toward projection lens 18, on a path parallel to optical axis O, for forming tiled quadrant III.
- 20 (iv) Modulated light for quadrant IV from illumination system 16d is modulated by spatial light modulator 20d to form modulated light beam 26d. Polarization beamsplitter 22b transmits modulated light beam 26d and beamsplitter 30 reflects modulated light beam 26d toward projection lens 18, on
- 25 a path parallel to optical axis O, for forming tiled quadrant IV.

Adjacent modulated light beams 26a, 26b, 26c, and 26d are directed toward projection lens 18 in parallel paths to output axis O. Unlike with prior art arrangements, modulated light beams 26a, 26b, 26c, and 26d are not centered onto the same optical axis by beam-combining elements. Instead,

30 modulated light beams 26a, 26b, 26c, and 26d are directed adjacently, in a non-overlapping manner. Certainly, some slight overlap is unavoidable between any two adjacent modulated light beams 26a, 26b, 26c, and 26d, necessary for

providing a suitable join or seam between adjacent image segments of tiled image 12. However, modulated light beams 26a, 26b, 26c, and 26d themselves are directed along separate, parallel axes rather than being centered onto the same optical axis O.

5 Analyzers 24a, 24b, 24c, and 24d are used in this embodiment to improve contrast for each tiled segment. Alternate arrangements for positioning analyzers 24a-24d are shown in subsequent embodiments.

Second Embodiment

Referring to Figure 3, there is shown an alternate component
10 arrangement for projection apparatus 10 in a second embodiment, using reflective spatial light modulators 20a-20d and using only two illumination systems 16a and 16b with beam aligner 40 for forming four quadrant tiled image 12 (not shown in Figure 3, but similar to that shown in Figure 1). For the beam-combining arrangement of Figure 3, illumination systems 16a and 16b both provide polarized
15 light along two parallel paths. Along one path, illumination system 16a provides S-polarized light; along the other parallel path, illumination system 16a provides P-polarized light. This light from illumination system 16a provides source illumination to a polarization beamsplitter 28a, a wire-grid polarization
20 beamsplitter in one embodiment. Polarization beamsplitter 28a separates light by its polarization state, directing light of one polarization state to polarization beamsplitter 22a for modulation by reflective spatial light modulator 20a. Output modulated light beam 26a from spatial light modulator 20a is then transmitted through polarization beamsplitter 22a and an analyzer 24a and through
25 polarization beamsplitter 22e and beamsplitter 30 to projection lens 18, in a path parallel to optical axis O, for forming tiled quadrant I. The other polarization state from polarization beamsplitter 28a goes through a half-wave plate 42 to alter its polarization state and is reflected toward reflective spatial light modulator 20b from polarization beamsplitter 22b. Output modulated light beam 26b is then transmitted through polarization beamsplitter 22b and an analyzer 24b, reflected
30 by polarization beamsplitter 22e, and transmitted through beamsplitter 30, in a path parallel to optical axis O, toward projection lens 18 for forming tiled quadrant II.

Formation of tiled quadrants III and IV is similar. Polarization beamsplitter 28b separates the polarized light along parallel paths from illumination system 16b by its polarization state, directing light of one polarization state to polarization beamsplitter 22c for modulation by reflective spatial light modulator 20c. Output modulated light beam 26c from spatial light modulator 20c is then transmitted through polarization beamsplitter 22c and through an analyzer 24c and is reflected by polarization beamsplitter 22f and beamsplitter 30, into a path parallel to optical axis O, to projection lens 18 for forming tiled quadrant III. The other polarization state from polarization beamsplitter 28b is transmitted through half-wave plate 42 to alter its polarization state, and toward reflective spatial light modulator 20d from polarization beamsplitter 22d. Output modulated light beam 26d is then transmitted through polarization beamsplitter 22d and an analyzer 24d and through polarization beamsplitter 22f, and is reflected by beamsplitter 30 into a path parallel to optical axis O, toward projection lens 18 for forming tiled quadrant IV.

Third Embodiment

Referring to Figure 4, there is shown a third embodiment of projection apparatus 10 of the present invention, using two separate illumination systems 16a and 16b that, in similar manner to the embodiment shown in Figure 3, provide light having orthogonal polarization states in separate paths, indicated as paths S and P. Polarized illumination system 16a provides light of both polarization states to polarization beamsplitter 22a, which directs the received illumination into separate paths for each polarization state. In the example of Figure 4, light having the S path polarization state is reflected toward reflective spatial light modulator 20a by polarization beamsplitter 22a. Light having the P path polarization state is transmitted toward spatial light modulator 20b. Modulated light beams 26a and 26b are then transmitted through beamsplitter 30, along adjacent paths parallel to optical axis O, toward lens 18 for forming tiled quadrants I and II respectively (as shown in Figure 1). Similarly, polarization beamsplitter 22b directs the received P and S path polarized illumination from illumination system 16b into separate paths for spatial light modulators 20c and 20d respectively. Modulated light beams 26c and 26d are then directed by

polarization beamsplitter 22b and reflected by beamsplitter 30, along adjacent paths parallel to optical axis O, toward projection lens 18 for forming tiled quadrants III and IV respectively (as shown in Figure 1).

Fourth Embodiment

5 Referring to Figure 5, there is shown an embodiment using two reflective spatial light modulators 20a and 20b for forming tiled image 12 having two tiled sections I and II. Figure 5 also shows an arrangement of illumination system 16 that provides separate paths for S- and P-polarized light, as is needed for the alternative embodiments of Figures 3 and 4. A light source 38, such as a
10 lamp or LED, for example, provides light to a polarization beamsplitter 32, typically through a uniformizer component of some kind, such as a lenslet array or integrator bar (not shown). Polarization beamsplitter 32 separates illumination into its orthogonal polarization states, and, using reflective surface 44 or a prism for redirecting light in the path of one of the polarization states, along spatially
15 separate paths S and P. Lenses 36 direct this light toward a single polarization beamsplitter 22 which serves as beam aligner 40. Light having one polarization state is transmitted directly through polarization beamsplitter 32 along a path S for modulation by spatial light modulator 20a. Light having the orthogonal polarization state is reflected by polarization beamsplitter 22 for modulation by
20 spatial light modulator 20b. Output modulated light is then directed from polarization beamsplitter 22 in the direction of optical axis O toward projection lens 18.

Fifth Embodiment

 Referring to Figure 6, there is shown an alternate embodiment for
25 projection using two transmissive spatial light modulators 20a and 20b for forming tiled image 12 having two tiled sections. As in the embodiment of Figure 5, polarization beamsplitter 32 and reflective surface 44 are provided as part of illumination system 16 to separate the illumination into its orthogonal polarization states, along spatially separate paths, P and S. Polarization beamsplitter 28 directs
30 one polarization state to transmissive spatial light modulator 20a, reflected by a turning mirror 34 in the embodiment of Figure 6. Light having the orthogonal polarization state is directed through polarization beamsplitter 28 and to

transmissive spatial light modulator 20b. Polarization beamsplitter 22, acting as beam aligner 40, then directs modulated light from both spatial light modulators 20a and 20b along adjacent paths, in the direction of optical axis O, toward projection lens 18.

5 The embodiments described hereinabove perform image tiling by alignment of modulated light beams 26a, 26b for forming adjacent image tiles, where this alignment is performed within the imaging subsystem of projection apparatus 10 itself, rather than requiring separate projection optics for each modulated light beam 26a, 26b, as with conventional tiling arrangements.

10 Alignment of multiple spatial light modulators 20 need only be performed at the time of manufacture, thereby simplifying the setup and use of projection apparatus 10 when compared with conventional techniques for alignment of individual projectors to achieve tiling.

 Projection lens 18 is a lens assembly that typically comprises a
15 plurality of lens elements, rather than a single lens component as is represented in Figures 1, 3, and 4. Beam aligner 40, in the various embodiments of Figures 1-6, may use a number of alternative arrangements of beamsplitters 30 and/or polarization beamsplitters 22, 28. It is instructive to observe again that beam aligner 40 provides a separate path for modulated light from each spatial light
20 modulator 20, with respective paths substantially non-overlapping.

 Illumination system 16 may derive polarized light from a xenon lamp, an LED, or other suitable component for providing illumination. Alternately, illumination system 16 may direct light through an optical fiber or other light-guiding component. Methods for providing polarized light could
25 employ polarization beamsplitter 32 in combination with reflective surface 44, as was shown in Figures 5 and 6, or other suitable components. The apparatus of the present invention could be employed for either monochrome or full-color imaging, using temporal sequencing of red, green, and blue light, each light provided separately to spatial light modulator 20, or some other method for
30 providing a modulated color beam along the optical paths shown in Figures 1-6. Temporal sequencing could be provided using a color filter wheel or using other techniques well known in the electronic image projection arts.

In the simplest embodiment, using only two tiled image segments, beam aligner 40 is a single component, polarization beamsplitter 22 as shown in Figures 5 and 6. For more complex embodiments used for projecting three or more tiled image segments, beam aligner 40 is formed as a more complex
5 arrangement of polarizing and conventional beamsplitters, with any number of suitable dichroic support elements, mirrors, and polarizing components, as shown in the embodiments of Figures 1, 3, and 4. It is instructive to note that the relative spatial positioning of spatial light modulators 20 is important, relative to the arrangement of beam aligner 40, for obtaining tiled image 12 with its separate
10 tiled segments properly placed and aligned.

The invention has been described in detail with particular reference to certain preferred embodiments thereof, but it will be understood that variations and modifications can be effected within the scope of the invention as described above, and as noted in the appended claims, by a person of ordinary skill in the art
15 without departing from the scope of the invention. For example, suitable polarization states and polarization components in the imaging path would be chosen for compatibility and performance, using techniques well known in the imaging arts. Different types of polarization beamsplitters could be used as components of beam aligner 40, including conventional MacNeille polarization
20 beamsplitters, as disclosed in U.S. Patent No. 2,403,731, (MacNeille) and wire-grid polarization beamsplitters, as disclosed in U.S. Patent No. 6,122,103 (Perkins et al.), for example.

Thus, what is provided is an apparatus and method for tiled projection display using spatial light modulators.

PARTS LIST

10	projection apparatus
12	tiled image
14	display surface
16	illumination system
16a	illumination system
16b	illumination system
16c	illumination system
16d	illumination system
18	projection lens
20	spatial light modulator
20a	spatial light modulator
20b	spatial light modulator
20c	spatial light modulator
20d	spatial light modulator
22	polarization beamsplitter
22a	polarization beamsplitter
22b	polarization beamsplitter
22c	polarization beamsplitter
22d	polarization beamsplitter
22e	polarization beamsplitter
22f	polarization beamsplitter
24a	analyzer
24b	analyzer
24c	analyzer
24d	analyzer
26a	modulated light beam
26b	modulated light beam
26c	modulated light beam
26d	modulated light beam
28	polarization beamsplitter
28a	polarization beamsplitter

28b	polarization beamsplitter
30	beamsplitter
32	polarization beamsplitter
34	mirror
36	lens
38	light source
40	beam aligner
42	half-wave plate
44	reflective surface